1.5 Transmitting Electrical Energy

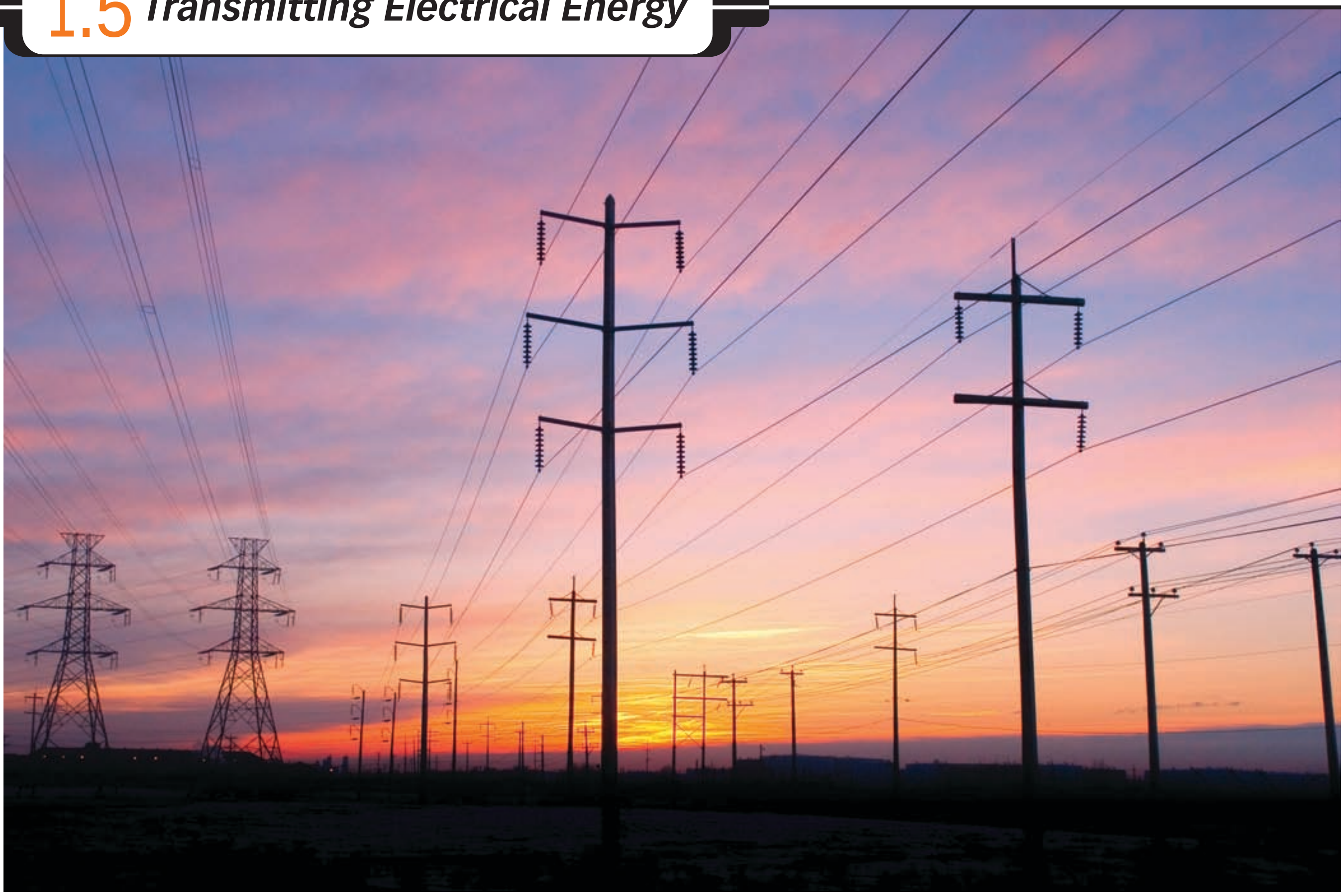


Figure C1.48

Most people take the convenience of electrical energy for granted. When you feel like a snack in the evening, you probably don't give much thought to flipping on the kitchen light before wandering over to the refrigerator to look for something to eat. It may appear that the source of energy for these devices is the household wiring; however, you know from your work earlier in the chapter that somewhere far away from where you live, the armature of a large generator is being forced to turn rapidly on its axis at a generating station. Transmission lines, like those in Figure C1.48, ensure that the energy produced at the generating station is available for you to use in your home.

The towers on the left side of Figure C1.48 support high-voltage transmission lines that typically operate with voltage values of well over 100 000 V. The guiding principle used by the engineers who design and operate the transmission system is to keep the voltage at the highest level possible while still being safe. Why is it so important for the voltage to be kept so high in transmission lines? How is this extremely high voltage converted into the 240 V used in most circuits? Why is the entire network that distributes electrical energy an AC system? In this lesson you will have an opportunity to answer these questions.

Power

Light bulbs and many other electrical devices are rated in terms of the electrical energy they consume every second. Recall that **power** is the quantity used to describe the rate of doing work or transforming energy.

work done (joules)

energy transformed (joules)

power (watts)

$$P = \frac{W}{t} = \frac{E}{t}$$

time interval (seconds)

Units: $1\ \text{W} = \dfrac{1\ \text{J}}{\text{s}}$

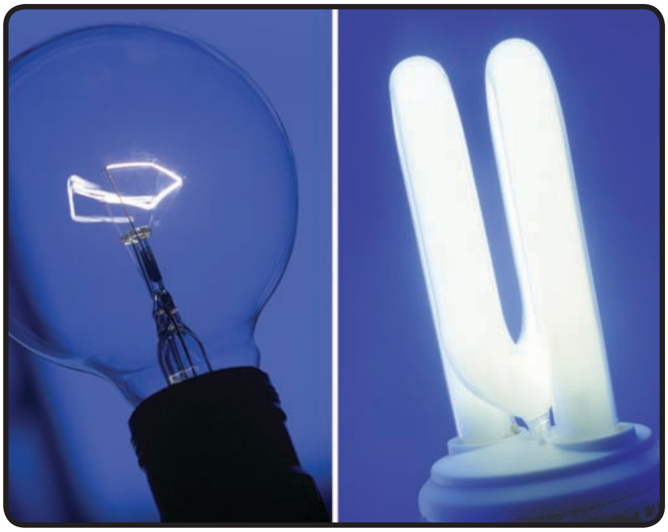


Figure C1.49: Conventional light bulbs are being replaced with more efficient designs that use less electrical energy to produce the same amount of light energy.

Most people are more familiar with the unit for power (the watt) than they are with the quantity itself. For example, a conventional 60-W light bulb transforms 60 J of electrical energy into thermal energy and light energy every second. Unfortunately, since most of the energy produced is thermal, these devices end up being heaters that also emit light. More efficient designs produce less thermal energy. This is reflected in the power rating: the 17-W compact fluorescent bulb shown in Figure C1.49 produces the same quantity of light energy as a conventional 60-W bulb. When it comes to lighting, the goal is to produce the required quantity of light energy while consuming the minimal quantity of electrical energy.

power: the rate of doing work or transforming energy

Example Problem 1.14

Two lamps emit the same quantity of light. One uses a 17-W compact fluorescent bulb, and the other uses a conventional 60-W bulb.

a. Calculate the electrical energy used by each bulb in 1.00 h.

b. Explain the following statement:

Compact fluorescent bulbs initially cost more to purchase, but throughout their lifetime they are less expensive to operate than conventional bulbs.

Solution

a. 60-W Conventional Light Bulb

$$P = 60\ \text{W} \\ = 60\ \text{J/s}$$

$$t = 1.00\ \cancel{\text{h}} \times \frac{60\ \cancel{\text{min}}}{1\ \cancel{\text{h}}} \times \frac{60\ \text{s}}{1\ \cancel{\text{min}}} \\ = 3.60 \times 10^3\ \text{s}$$

$$E = ?$$

$$P = \frac{E}{t}$$

$$E = Pt \\ = (60\ \text{J/s})(3.60 \times 10^3\ \text{s}) \\ = 2.2 \times 10^5\ \text{J}$$

The conventional 60-W light bulb uses 2.2×10^5 J of electrical energy in 1.0 h.

17-W Compact Fluorescent Light Bulb

$$P = 17\ \text{W} \\ = 17\ \text{J/s}$$

$$t = 1.00\ \cancel{\text{h}} \times \frac{60\ \cancel{\text{min}}}{1\ \cancel{\text{h}}} \times \frac{60\ \text{s}}{1\ \cancel{\text{min}}} \\ = 3.60 \times 10^3\ \text{s}$$

$$E = ?$$

$$P = \frac{E}{t}$$

$$E = Pt \\ = (17\ \text{J/s})(3.60 \times 10^3\ \text{s}) \\ = 6.1 \times 10^4\ \text{J}$$

The 17-W bulb uses 6.1×10^4 J of electrical energy in 1.0 h.

b. The compact fluorescent bulb uses less electrical energy to produce the same quantity of light energy. Since electrical energy is purchased and paid for on a monthly bill, the total operating cost for a compact fluorescent bulb is less than that of a conventional bulb.

Practice

39. A family shopping for a new refrigerator has narrowed its search down to two possibilities. The first model is rated at 700 W, and the second is rated at 500 W.

a. Determine the quantity of electrical energy used by each model in a day. Assume that each model runs for 6.0 h every day.

b. The manufacturer of the 500-W model promotes their model as being “an environmentally friendly alternative.” Refer to your answer to question 39.a. to explain the meaning of this statement.

Power in Electrical Systems

Someone whose hobby is car audio systems may describe the power rating of his or her speakers as 300 W. In this case, the power rating describes the maximum safe input of electrical energy required to produce sound energy. In fact, power is a quantity that is used so frequently in such a wide variety of electrical applications that special equations have been developed to describe power in terms of electric circuits, voltage, and electric current. Units provide a helpful insight into the origins of these equations:

Calculating Power in Electrical Systems

V
- voltage
- measured in joules per coulomb

$\mathrm{J/C}$

I
- electric current
- measured in coulombs per second

$\mathrm{C/s}$

$$= \mathrm{J}/\cancel{\mathrm{C}} \times \cancel{\mathrm{C}}/\mathrm{s}$$
$$= \mathrm{J/s}$$

Since J/s is the unit for power, the unit analysis suggests the following equation:

$$\underset{\text{power (watts)}}{P} = \underset{\text{voltage (volts)}}{V}\,\underset{\text{electric current (amperes)}}{I}$$

Units: $1\ \mathrm{W} = 1\ \mathrm{V{\bullet}A}$

This equation is very useful because voltage and electric current are quantities frequently used to describe the characteristics of electric circuits. Car audio circuits are no exception, since the electrical signals sent to the speakers are also described in terms of voltage and electric current. A speaker is basically a large-scale version of the tiny earpiece of the headphones you studied earlier.

Just like headphones, a speaker is an AC device that only operates if the electric current changes directions. In this course, a simplified approach is taken that assumes the coil of the speaker acts as a constant source of resistance.

In reality, the resistance of a speaker can vary depending upon how frequently the AC signal switches directions and upon the characteristics of other components in the circuit. Example Problems 1.15 and 1.16 show how this simplified approach can be applied.

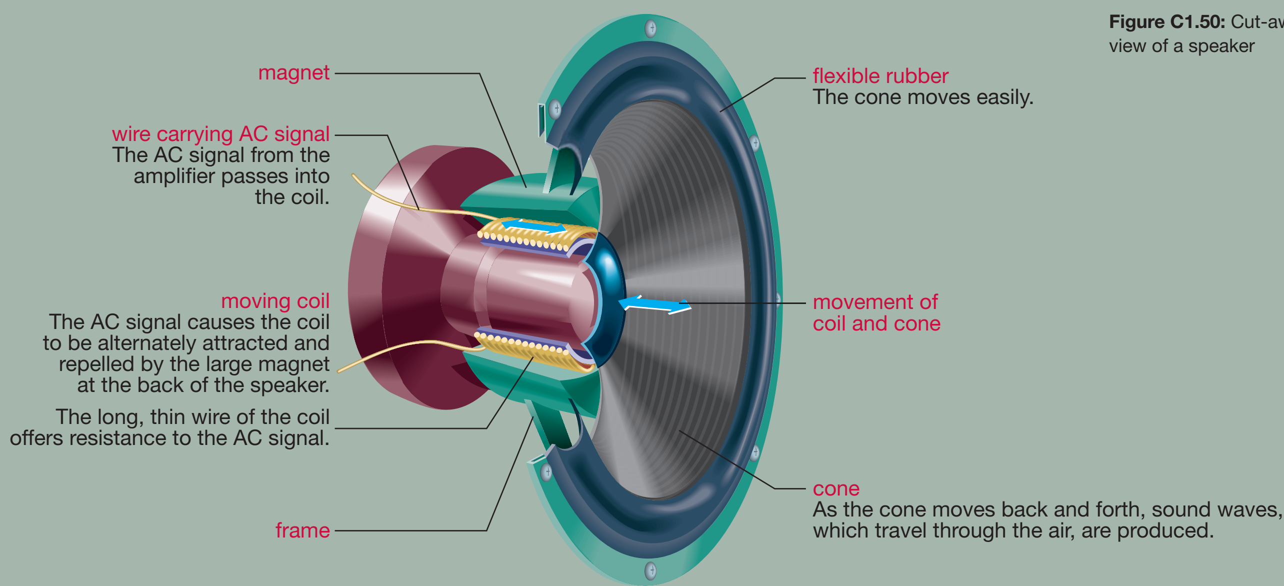


Figure C1.50: Cut-away view of a speaker

Example Problem 1.15

Using a simplified approach, a speaker can be treated as a device that offers 4.0 Ω of resistance to the AC input signal, allowing only 2.00 A of current to flow. Calculate the power consumed by the speaker.

Solution

step 1: Calculate the voltage applied across the wires of the speaker.

$R = 4.0\ \Omega$

$I = 2.00\ \text{A}$

$V = ?$

$$\begin{aligned} V &= IR \\ &= (2.00\ \text{A})(4.0\ \Omega) \\ &= 8.0\ \text{V} \end{aligned}$$

The AC voltage applied across the wires of the speaker is 8.0 V.

step 2: Calculate the power consumed by the speaker.

$V = 8.0\ \text{V}$

$I = 2.00\ \text{A}$

$P = ?$

$$\begin{aligned} P &= VI \\ &= (8.0\ \text{V})(2.00\ \text{A}) \\ &= 16\ \text{W} \end{aligned}$$

The power consumed by this speaker is 16 W.

Example Problem 1.16

The volume is turned up in a car with a 4.0-Ω speaker so that 4.50 A of alternating current flows to the speaker. Calculate the power consumed by this speaker.

Solution

$R = 4.0\ \Omega$

$I = 4.50\ \text{A}$

$P = ?$

$$\begin{aligned} P &= I^2R \\ &= (4.50\ \text{A})^2(4.0\ \Omega) \\ &= 81\ \text{W} \end{aligned}$$

The power consumed by the speaker is 81 W.

The solution to Example Problem 1.15 required two steps because the voltage was given. Note how the first step of the solution used Ohm's law. Since there are so many cases where power needs to be calculated but voltage is unknown, another version of the power equation has been developed.

$\boxed{P = VI}$ $\boxed{V = IR}$

Substitution

$$P = (IR)I$$

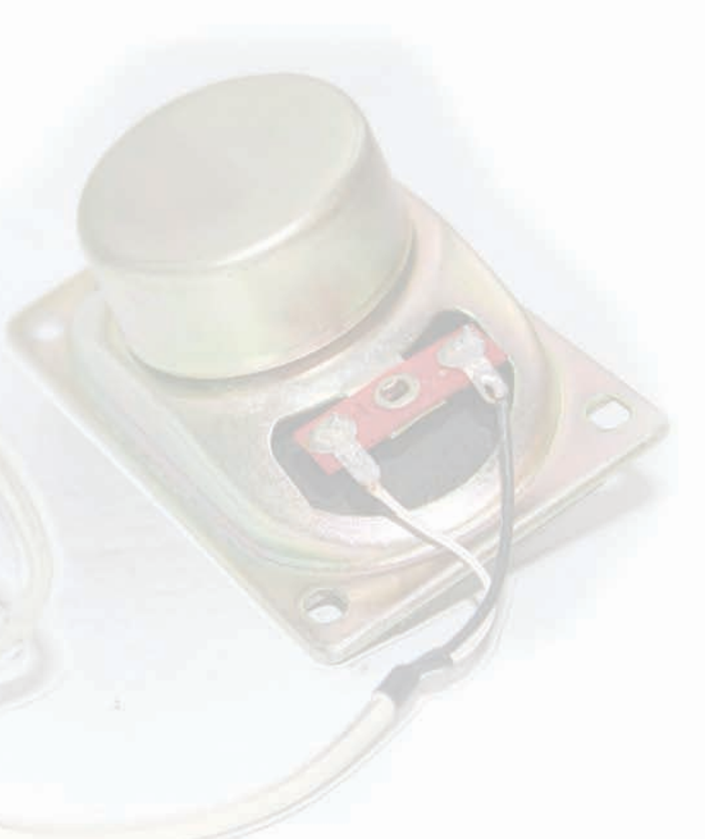
electric current (amperes)

power (watts) → $P = I^2R$ ← resistance (ohms)

Units: $1\ \text{W} = \text{A}^2\ \Omega$

This version of the power equation is very convenient because the power can be calculated in one step in cases where the voltage is not given.

Example Problem 1.16 used the simplified approach of treating a speaker as a device that offers a constant resistance to an AC input signal. The results of these calculations give very good estimates of the power requirements of speakers. In fact, this simplified approach can also be used when determining how sets of speakers will behave when they are connected in series or in parallel.



Practice

40. Solve Example Problem 1.15 using a one-step approach. Confirm that you get the same answer using this method.

41. Solve Example Problem 1.16 using a two-step approach. Confirm that you get the same answer using this method.

Use the following information to answer questions 42 to 44.

One of the circuits in a car audio system involves a specialized speaker called a subwoofer, which is designed to produce very low-frequency sounds. This is the speaker that is responsible for the thumping bass that can often be heard some distance away from a vehicle. In Figure C1.51, the subwoofers are the four largest speakers.

Figure C1.51

Each subwoofer can be treated as a device that maintains a constant resistance of 8.0 Ω in these questions.

42. Two of the subwoofers are connected in parallel to one of the circuits in the sound system. This circuit uses a circuit breaker to ensure that the maximum current that can be drawn from the amplifier is 5.0 A.

a. Draw a schematic diagram for the circuit involving the two subwoofers and the circuit breaker.

b. Determine the total resistance of the two speakers in this circuit.

c. Use your answer to question 42.b. to determine the power consumed by the two speakers if they draw the maximum current of 5.0 A.

d. Use two different equations to verify that the sound system is supplying 20.0 V to the two speakers under these conditions.

43. Suppose the two speakers are connected in series with a circuit breaker to the same 20.0-V output of the amplifier.

a. Draw a schematic diagram for the circuit breaker and the two speakers connected in series.

b. Determine the total resistance of the two speakers in this circuit.

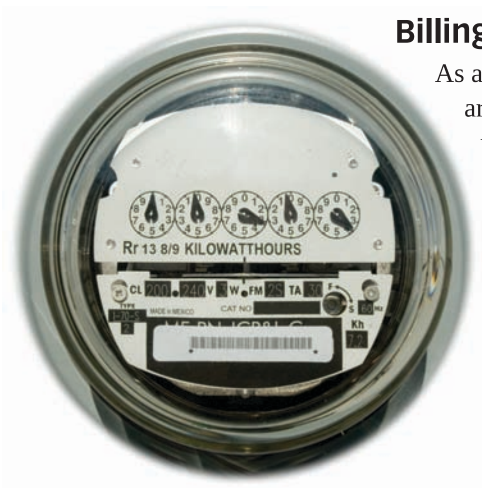
c. Calculate the total current drawn by the speakers in this circuit.

d. Calculate the power consumed by the two speakers in this circuit.

44. Refer to your answers to questions 42 and 43.

a. If the goal was to produce the most sound energy from the 20-V input signal, would it be better to connect the speakers in series or in parallel?

b. Is there a disadvantage to the type of connection that you identified in question 44.a?



Billing Consumers for Electrical Energy

As anyone who has paid an electricity bill knows, electrical energy is not free. Meters are used by utility companies to monitor the use of electrical energy, which is then used to calculate the bill that is mailed to the consumer. The traditional unit used by utility companies is the **kilowatt-hour**.

As shown by the following equations, the kilowatt-hour is an energy unit derived from rearranging the equation for electric power.

kilowatt-hour: the traditional unit for electrical energy used by utility companies; 1 kW•h = 3.6 MJ

$$P = \frac{E}{t}$$

$$E = Pt$$

energy measured in kilowatt-hours = power measured in kilowatts × time measured in hours

Example Problem 1.17

A kettle rated at 1000 W operates for a total of 60.0 min in a typical week.

a. Determine the energy consumed in kilowatt-hours.

b. Determine the energy consumed in joules.

c. State the relationship between kilowatt-hours and joules.

d. Use your answer to part c. to show an alternative method of answering part b. by using your answer to part a.

Solution

a.
$$P = 1000\ \cancel{\text{W}} \times \frac{1\ \text{kW}}{1000\ \cancel{\text{W}}} = 1.000\ \text{kW}$$

$$t = 60.0\ \cancel{\text{min}} \times \frac{1\ \text{h}}{60\ \cancel{\text{min}}} = 1.00\ \text{h}$$

$$E = ?$$

$$P = \frac{E}{t}$$

$$E = Pt = (1.000\ \text{kW})(1.00\ \text{h}) = 1.00\ \text{kW•h}$$

The appliance consumed 1.00 kW•h of energy.

b.
$$P = 1000\ \cancel{\text{W}} \times \frac{1\ \text{J/s}}{1\ \cancel{\text{W}}} = 1000\ \text{J/s}$$

$$t = 60.0\ \cancel{\text{min}} \times \frac{60\ \text{s}}{1\ \cancel{\text{min}}} = 3.60 \times 10^3\ \text{s}$$

$$E = ?$$

$$P = \frac{E}{t}$$

$$E = Pt = (1000\ \text{J/s})(3.60 \times 10^3\ \text{s}) = 3.60 \times 10^6\ \text{J} = 3.60\ \text{MJ}$$

The appliance consumed 3.60×10^6 J or 3.60 MJ of energy.

c. The answers to parts a. and b. indicate that 1.00 kW•h = 3.60×10^6 J = 3.6 MJ.

d.
$$E = 1.00\ \cancel{\text{kW•h}} \times \frac{3.6 \times 10^6\ \text{J}}{1\ \cancel{\text{kW•h}}} = 3.6 \times 10^6\ \text{J}$$

Calculating the Cost of Electricity in Dollars

As Example Problem 1.17 shows, 1 kW•h is equivalent to 3.6×10^6 J or 3.6 MJ. The fact that the kilowatt-hour represents such a large quantity of energy is one of the reasons this unit is used by utility companies to bill customers. The cost of a kilowatt-hour varies, depending upon where you live and the current state of the electricity market. At the time this textbook was written, many Albertans were paying about 9.3¢/kW•h.

Example Problem 1.18

Most models of TVs and VCRs use electrical energy even when they are turned off. This stand-by power is used to run clocks in VCRs and to provide an "instant on" feature, allowing home electronics to become operational with a click of the remote control. Average values for stand-by power are about 3.0 W for a VCR and 5.0 W for a TV. Since this power is required 24 h a day, the electrical energy consumption is significant.

a. Determine the electrical energy required to supply 8.0 W of stand-by power for both a TV and a VCR during one year. Express your answer in kilowatt-hours.

b. If the price of electricity is 9.3¢/kW•h, determine the cost in dollars of providing stand-by power to the VCR and TV for 365 days (one year).

c. There are about 2.0 million TVs and VCRs that operate with stand-by power in Alberta. Use this fact to estimate the total annual cost of maintaining stand-by power for all of these devices in Alberta.

Solution

a.

$$P = 8.0\ \cancel{\text{W}} \times \frac{1\ \text{kW}}{1000\ \cancel{\text{W}}} = 8.0 \times 10^{-3}\ \text{kW}$$

$$t = 365\ \cancel{\text{d}} \times \frac{24\ \text{h}}{1\ \cancel{\text{d}}} = 8.76 \times 10^{3}\ \text{h}$$

$E = ?$

$$P = \frac{E}{t}$$

$$E = Pt = (8.0 \times 10^{-3}\ \text{kW})(8.76 \times 10^{3}\ \text{h}) = 70.08\ \text{kW}\bullet\text{h} = 70\ \text{kW}\bullet\text{h}$$

The energy required to supply the stand-by power for one year is 70 kW•h.

b. units of energy = 70.08 kW•h

cost per energy unit = 9.3¢/kW•h = \$0.093/kW•h

cost of energy = ?

cost of energy = units of energy × cost per energy unit
= (70.08 kW•h)(\$0.093/kW•h)
= \$6.52

The annual cost of maintaining the stand-by power for the combination of a VCR and a TV is \$6.52.

c. number of TVs and VCRs in Alberta = 2.0 million

annual cost for 1 TV and 1 VCR = \$6.52

annual cost for all TVs and VCRs in Alberta = ?

annual cost for all TVs and VCRs in Alberta = number of TVs and VCRs in Alberta × annual cost for 1 TV and 1 VCR
= (2.0 million)(\$6.52)
= \$13 million

The annual cost to provide stand-by power for all the TVs and VCRs in Alberta is about \$13 million.

Practice

45. Compile a list of all the devices in your home that use stand-by power. To determine whether a device uses stand-by power, the following criteria may be helpful:

- It uses a stand-alone power supply, like an AC adaptor.
- It has a remote control.
- It has a soft-touch keypad.
- It charges the battery of a portable device, like a cordless phone.
- It is warm to the touch even when it is turned off.
- It does not have an "off" switch.
- It has a digital clock display.

46. After listing all the devices in her home that use stand-by power, Mikaila determines that the total stand-by power consumed by the appliances in her household is 87 W.

a. Determine the total energy (in kW•h) required to supply all the appliances in this household with stand-by power for 365 days (one year).

b. If the price of electricity is 9.3¢/kW•h, determine the annual cost (in dollars) of the electrical energy required to supply the stand-by power for this household.

c. Describe how the use of stand-by power impacts the environment.

Calculating Some of the Environmental Costs of Electricity

Figure C1.52: The Genesee generating station near Edmonton uses the combustion of pulverized coal to produce electricity.

In Alberta, about 75% of the electricity generated is produced at generating stations that burn coal. The energy released from the combustion of the coal is used to produce high-pressure steam that drives a turbine connected to the armature of a large generator.

In the traditional, coal-fired generating stations currently in operation today, the coal is first pulverized into a fine powder before it is burned to produce steam. As you learned in a previous unit, the products of this combustion reaction include carbon dioxide (CO_2); sulfur oxides (SO_x); nitrogen oxides (NO_x); particulate matter; and trace amounts of other compounds, including mercury.

Figure C1.53: This generating station in Florida looks more like a refinery because the coal is first converted into synthetic gas, or syngas. The syngas is cleaned before it is burned.

New technologies are being used to reduce the environmental impact of burning coal to produce electricity. Experimental, low-emission generating stations first convert the coal into a hydrocarbon vapour called synthetic gas, or syngas for short. The syngas is then stripped of impurities before it is burned to produce the steam that drives the turbine, which is connected to the armature of the generator. As the following table demonstrates, new technologies are helping to reduce some of the harmful effects of coal as a source of energy.

COMPARING COAL-COMBUSTION TECHNOLOGIES

Type of Emission	Mass Released Generating Electrical Energy (g/kW•h)	
	Traditional Generating Station	Experimental, Low-Emission Generating Station†
CO_2(g)	about 1.0×10^3	less than 8.0×10^2
SO_x(g)	less than 1.9*	less than 0.2
NO_x(g)	less than 1.4*	less than 0.05
particulate matter	less than 0.14*	less than 0.03

* Maximum value allowed under Alberta Emission Standards (2001)
† Data from experimental, low-emission generating stations

The table "Comparing Coal-Combustion Technologies" is a rich source of information that answers some questions and suggests some new ones. Note that the new coal-combustion technologies dramatically reduce the emissions of sulfur oxides, nitrogen oxides, and particulate matter; but the reductions in carbon dioxide are much more modest. Although it is possible to use scrubbers and other technologies to remove impurities from the coal, the one thing that cannot be removed is the energy-rich hydrocarbon compounds that are the essential component of coal as a fuel. Since coal is the starting point in both systems, the ability to reduce carbon dioxide emissions has its limitations. Given the connections between carbon dioxide emissions and global climate change, some people are hesitant to embrace new coal-combustion technologies.

The next table shows data for when natural gas is burned in a gas turbine coupled to the armature of a generator. The hot exhaust gas is used to produce steam that can also produce electricity using a steam turbine connected to the armature of a generator.

NATURAL GAS-COMBUSTION TECHNOLOGY

Type of Emission	Mass Released Generating Electrical Energy (g/kW•h)*
CO_2(g)	about 4.0×10^2
SO_x(g)	less than 0.003
NO_x(g)	less than 0.01
particulate matter	less than 0.02

* Data from natural gas combined-cycle generating stations

Figure C1.54: An electrical engineer supervises operations at a generating station.

One way to significantly reduce the amount of carbon dioxide emissions from combustion reactions is to start with a different fuel. When natural gas is used as fuel for generating electricity, the amount of carbon dioxide released is about 400 g/kW•h, which is about half of the best values produced by the most advanced coal-combustion technologies. Since natural gas has already been cleaned of sulfur, and special burners can reduce the emission of nitrogen oxides, many people regard the existing natural gas-fired generating stations as being a better choice for the environment than the leading-edge, coal-fired options.

These tables provide only a glimpse of some of the environmental consequences of using fossil fuels to generate electricity. Although it is certainly possible to dig deeper into the technical data supporting the use of one technology over another, it is also important to step back and keep the big picture in mind by considering people's use of electrical energy.

Figure C1.55: It has been estimated that about 80% of the energy consumed by a typical microwave oven in its lifetime is used for its clock and stand-by power.

Is it really necessary for so many appliances to have electronic displays and clocks that use electrical energy on a continual basis? Although newer standards are reducing the energy consumed by products that use stand-by power, these efforts are offset by an increasing number of products, like dishwashers, washers, and dryers, that are starting to utilize electronic displays and, therefore, require stand-by power. Unfortunately, many observers of these trends suspect that the stand-by power consumed by each household will continue to increase.

Practice

Use the following information to answer questions 47, 48, and 49.

An Alberta family used about 1.05×10^4 kW•h of electrical energy last year. This use of energy has a significant effect on the family budget because they pay 8.8¢/kW•h.

47. Assume that the electric utility company generates electricity using a traditional coal-fired generating station, where the coal is pulverized into a powder and then burned to produce steam to drive a generator.

a. Use the tables "Comparing Coal-Combustion Technologies" and "Natural Gas-Combustion Technology" to estimate the mass (in kilograms) of the annual emissions of CO_2(g), SO_x(g), NO_x(g), and particulate matter that are a consequence of this family's electricity use.

b. Calculate the annual cost (in dollars) of electrical energy for this family.

48. Careful inspection of the electrical devices reveals that a total of 85 W of power is consumed to maintain stand-by power in this family's home.

a. Determine the electrical energy (in kilowatt-hours) consumed on an annual basis to maintain the stand-by power in the electrical devices used by this family.

b. Determine the percentage of this family's annual electric utility bill and the percentage of the corresponding annual emissions into the environment that can be traced to the consumption of stand-by power.

49. List some of the strategies this family could use to reduce the consumption of electrical energy and the corresponding emissions into the environment.

Transmitting Electrical Energy

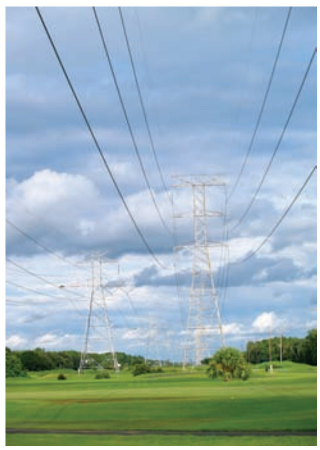
Consumers are not the only people interested in reducing the wasteful use of electrical energy. Electric utility companies have designed their transmission and distribution systems to minimize energy losses. Every kilowatt-hour that is lost in the transmission process from the generating station to your home represents a loss in profit as well as a step backward in the efforts of the utility company to meet environmental regulations. The main source of power loss in the electrical distribution system is the heat produced by the electric current passing through many kilometres of conducting cables. The following equation identifies the key factors affecting these power losses.

power lost in the cables due to heating effects (watts)

resistance of kilometres of cable (ohms)

$$P = I^2R$$

current passing through the cables (amperes)



Once the resistance of the cables has been made as low as possible, the only way to reduce power losses is to keep the current to a minimum.

Note that the value of the electric current is squared in the equation $P = I^2R$. This means that any reductions in the electric current will dramatically reduce power losses due to heating within the cables. The engineers who design electric power-distribution systems put this strategy into action by increasing the voltage within the transmission system. The thinking behind this approach is illustrated in Example Problems 1.19 and 1.20.

Example Problem 1.19

A 100-km length of transmission cable has a resistance of 5.0 Ω. This cable transmits 500 kW of power from the generator to a small town.

a. Determine the electric current required to transmit the 500 kW of power if the voltage used within the system is 5000 V.

b. Use your answer to part a. to calculate the power lost due to heating effects through the 100 km of conducting cable.

c. Use your answer to part b. to determine the percentage of the transmitted power that was lost due to heating effects in this arrangement.

Solution

a. $P = 500\ \cancel{\text{kW}} \times \dfrac{1000\ \text{W}}{1\ \cancel{\text{kW}}}$

$= 5.00 \times 10^5\ \text{W}$

$V = 5000\ \text{V}$

$I = ?$

$P = IV$

$I = \dfrac{P}{V}$

$= \dfrac{5.00 \times 10^5\ \text{W}}{5000\ \text{V}}$

$= 100\ \text{A}$

The electric current required is 100 A.

b. $I = 100\ \text{A}$

$R = 5.0\ \Omega$

$P = ?$

$P = I^2R$

$= (100\ \text{A})^2(5.0\ \Omega)$

$= 5.0 \times 10^4\ \text{W}$

The power lost due to heating effects within the cable is 5.0×10^4 W.

c. transmitted power = 5.00×10^5 W

power lost to heating = 5.0×10^4 W

% of power lost = ?

$$\%\text{ of power lost} = \frac{\text{power lost to heating}}{\text{transmitted power}} \times 100\%$$

$$= \frac{5.0 \times 10^4\ \text{W}}{5.00 \times 10^5\ \text{W}} \times 100\%$$

$$= 10\%$$

In this system, 10% of the available power was lost due to heating effects within the transmission cables.

Example Problem 1.20

Repeat the analysis of Example Problem 1.19 by increasing the voltage within the system to 50 000 V.

Solution

a. $P = 500\ \cancel{\text{kW}} \times \dfrac{1000\ \text{W}}{1\ \cancel{\text{kW}}}$

$= 5.00 \times 10^5\ \text{W}$

$V = 50\ 000\ \text{V}$

$I = ?$

$P = IV$

$I = \dfrac{P}{V}$

$= \dfrac{5.00 \times 10^5\ \text{W}}{50\ 000\ \text{V}}$

$= 10.0\ \text{A}$

The electric current required is 10.0 A.

b. $I = 10.0\ \text{A}$

$R = 5.0\ \Omega$

$P = ?$

$P = I^2R$

$= (10.0\ \text{A})^2(5.0\ \Omega)$

$= 5.0 \times 10^2\ \text{W}$

The power lost due to heating effects within the cable is 5.0×10^2 W.

c. transmitted power = 5.00×10^5 W

power lost to heating = 5.0×10^2 W

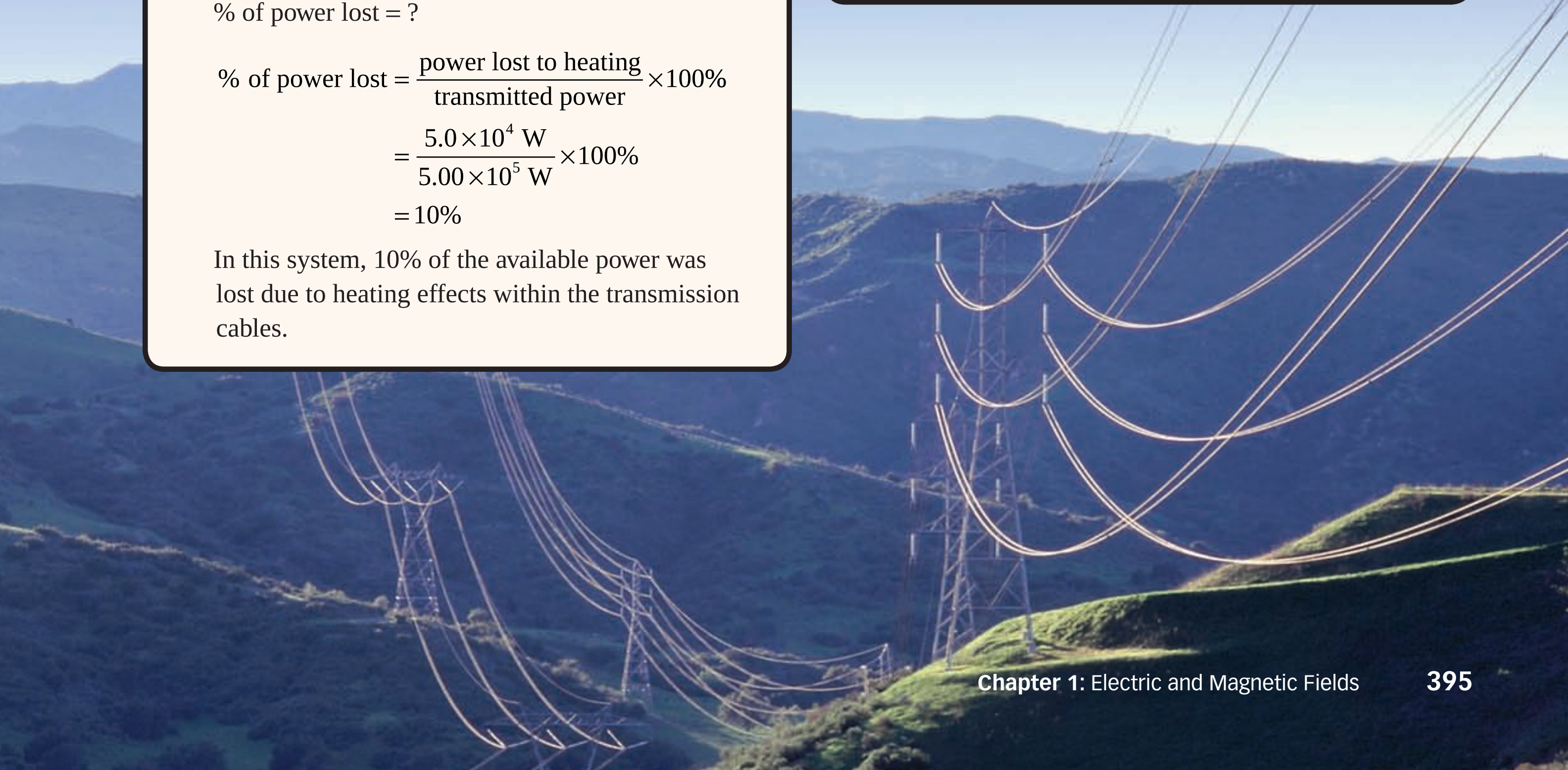
% of power lost = ?

$$\%\text{ of power lost} = \frac{\text{power lost to heating}}{\text{transmitted power}} \times 100\%$$

$$= \frac{5.0 \times 10^2\ \text{W}}{5.00 \times 10^5\ \text{W}} \times 100\%$$

$$= 0.10\%$$

In this system, 0.10% of the available power was lost due to heating effects within the transmission cables.



Transforming Voltages

As the calculations in Example Problems 1.19 and 1.20 demonstrate, less power is lost to heating effects within the conducting cables if the transmission system minimizes the electric current by using high voltages. Depending upon the amount of power that is being transmitted, the voltages used on the main conducting cables can be as high as 500 kV. Although these ultra-high voltage values are ideal for transmitting electrical energy, they are many times higher than the 240 V or 120 V typically used in homes. Since nearly every home is fed electrical energy from the main transmission system, it is natural to wonder how the ultra-high transmission voltages are transformed into the much lower values used in homes.

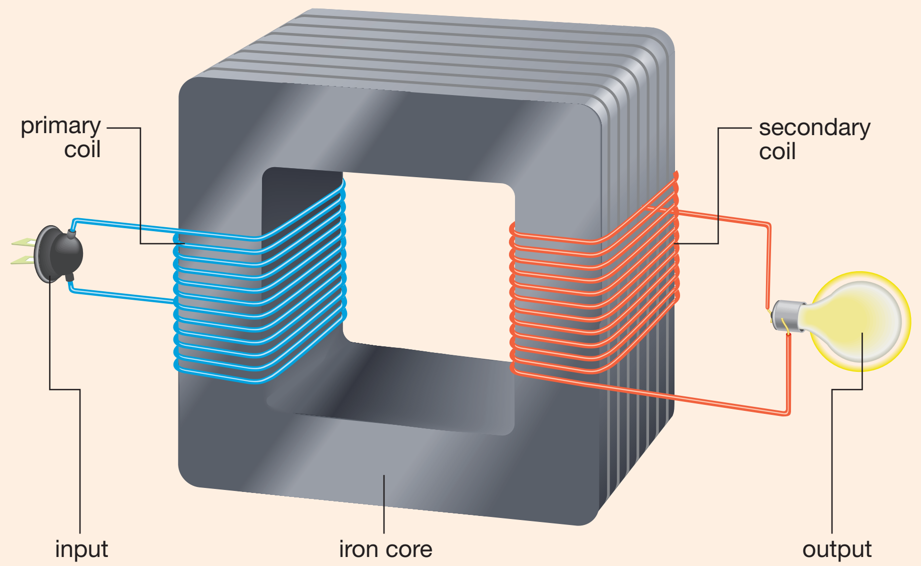
The transmission voltages are reduced by a number of devices called **transformers**. As the name suggests, a transformer transforms the voltage value of one circuit into a different value to be used by another circuit. Each of the large cylindrical devices on the power pole in the photograph is called a step-down transformer because it reduces the voltage on the primary circuit (in this case about 4 kV) to a lower value that will enter homes—typically 240 V, which is then split into the 120 V used by most household circuits.

transformer: a device that transforms the AC voltage of one circuit into a different AC voltage for another circuit using separate coils of wire wound around a common iron core

This transformer increases the voltage from the 20 kV produced at the generating station to the ultra-high voltages (500 kV or 230 kV) used for the transmission of electrical energy. Since the voltage is increasing, this device is referred to as a step-up transformer.

Key Components of a Transformer

The essential design of a transformer involves two coils of insulated wire, each wrapped around a common core of laminated iron. The **primary coil** receives the input voltage from some external source, which causes a current to flow. The primary current and the primary voltage remain within the primary coil because the wire of this circuit is insulated. Although the **secondary coil** is a separate circuit that does not contact the primary circuit, the secondary current and the secondary voltage of this coil are a result of the electric current in the primary coil. How is the primary coil able to influence the charges within the secondary coil if they are separate circuits with no electrical connection between the two? You will have an opportunity to discover the answer to this question in the next investigation.



primary coil: the coil to which the input voltage is applied in a transformer

secondary coil: the coil that supplies the output voltage of a transformer

Investigation

Exploring the Transformer

Science Skills

✓ Performing and Recording

✓ Analyzing and Interpreting

Purpose

You will build a simple transformer and observe its operation.

CAUTION!

This investigation involves briefly passing a current through the coil that you build. The coil will become warm and remain that way for a few seconds after the current has passed. If the coil is left connected for more than a few seconds, it will become uncomfortably warm and will unnecessarily drain the batteries. Allow the current to pass through the coil for only a few seconds at a time.

Materials

- 4 AA cells in a plastic battery pack with leads
- digital multimeter
- cardboard cylinder, about 4 cm in diameter and 10 cm in length (empty toilet-tissue roll)
- 2, 10-m pieces of 26- or 28-gauge enamelled magnet wire
- 4 test leads with alligator clips at each end
- strong bar magnet
- iron rod from a ring stand
- small knife
- adhesive tape

Procedure and Observations

step 1: Wrap 10 m of enamelled magnet wire around the cardboard cylinder to make a small coil. Leave about 10 cm of wire free from each end to act as contacts. Use adhesive tape to hold the contacts and the coils in place. Use a small knife to carefully scrape the enamel coating from the last 5 cm of each contact, as shown in Figure C1.56.

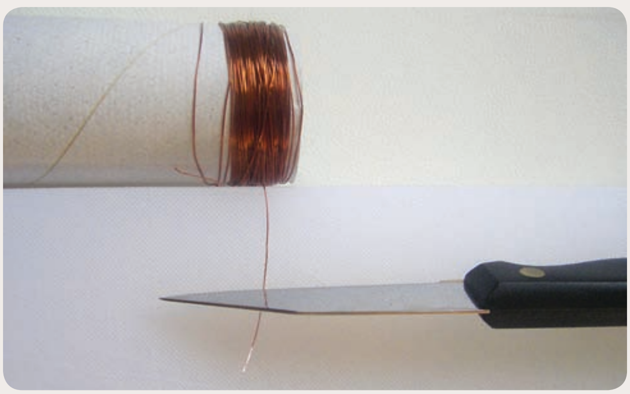


Figure C1.56

step 2: Repeat step 1 and build a second coil. Label one coil as the secondary coil and the other as the primary coil.

step 3: Connect the secondary coil to the digital multimeter. Set up the multimeter so it is able to measure DC millivolts. While observing the reading on the multimeter, move one end of the bar magnet toward and away from the secondary coil, as shown in Figure C1.57. Record your observations.

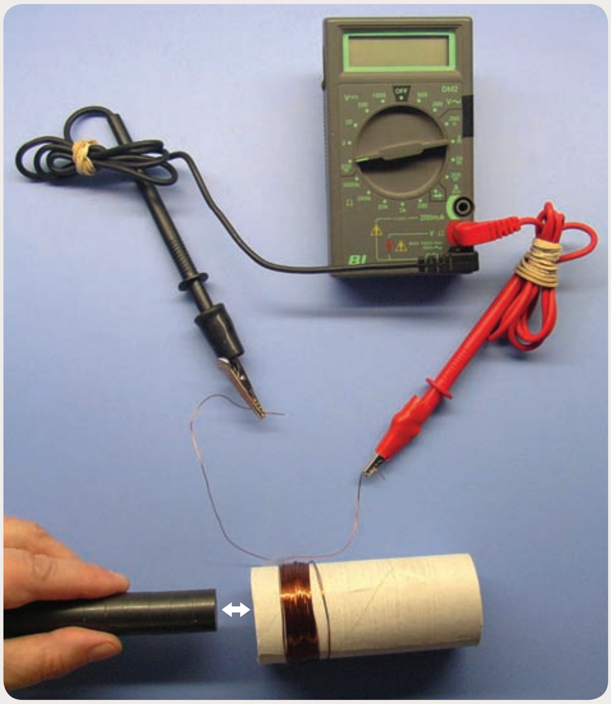


Figure C1.57

step 4: Use the equipment described in step 3 to determine which circumstances produce the largest output on the multimeter and which circumstances produce no output on the multimeter. Record your observations.

step 5: Set up the apparatus as shown in Figure C1.58.

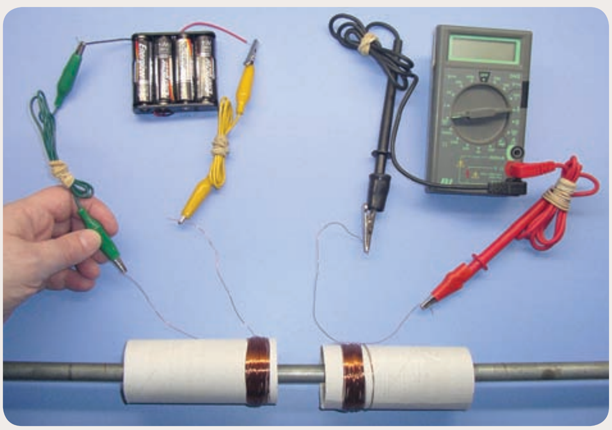
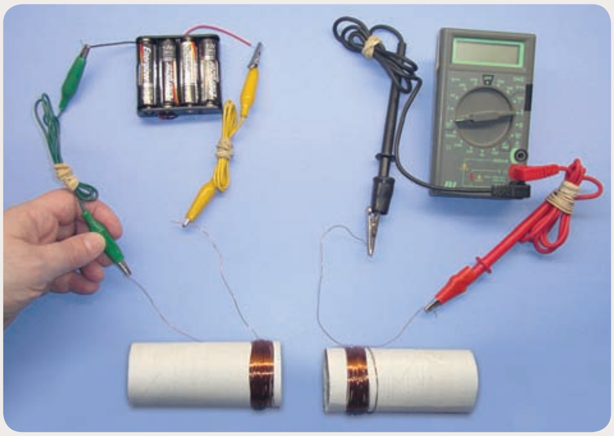


Figure C1.58

step 6: Connect one of the leads from the primary coil to one of the leads of the battery pack. While carefully observing the display on the digital multimeter, momentarily connect the other contact from the primary coil to the battery pack. Use the multimeter to observe the effects on the secondary coil when contact is first made. After only a few seconds of contact, break the connection and use the multimeter to observe the effects on the secondary coil when contact is broken.

step 7: Repeat steps 5 and 6 with the iron rod removed from the centres of the two coils.



Analysis

1. Review your observations from step 3, when you moved the magnet in and out of the secondary coil.

   a. Was the secondary coil acting as a motor or a generator?

   b. Although the magnet did not touch the secondary coil, a current was induced in the secondary coil. Explain how this effect was able to occur.

2. Review your observations from step 4, when you determined which circumstances produced the maximum and minimum effect on the secondary coil. Summarize your findings.

3. Review your observations from step 6, when you made intermittent contact with the battery pack and the primary coil while using the multimeter to observe the effects on the secondary coil. Although the primary coil did not touch the secondary coil, there was an effect on the secondary coil. Explain how this effect was able to occur.

4. Review your observations from step 7. Suggest a reason why it is important for a transformer to have an iron core.

Describing the Operation of a Transformer

In the “Exploring the Transformer” investigation, you observed that the secondary coil is affected by the primary coil only if current within the primary coil is changing. If a switch connecting the primary coil to a battery pack is suddenly closed, an increasing magnetic field is produced within the secondary coil.

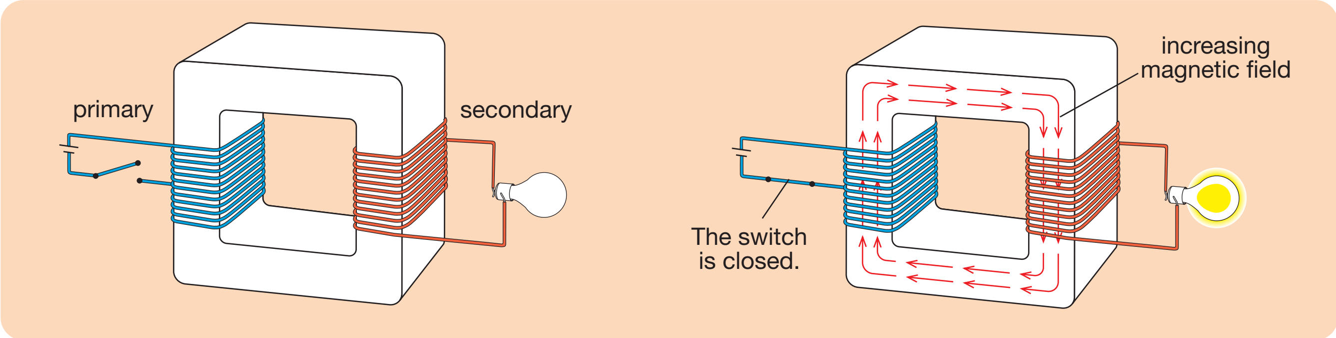


Figure C1.59: Closing the switch causes the current in the primary coil to increase. The magnetic field increases through the secondary coil. A current is induced to flow in the secondary coil.

It is the changing magnetic field within the secondary coil that is central to this process. As long as the magnetic field is changing, a current will be induced in the secondary coil. Since decreasing the magnetic field is also a change, opening the switch can cause a current to be induced in the secondary coil.

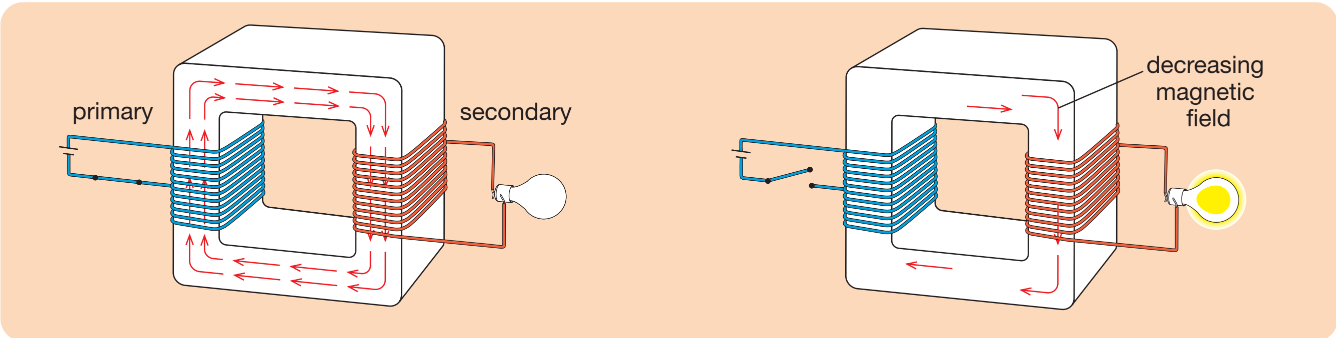


Figure C1.60: Opening the switch causes the current in the primary coil to decrease. The magnetic field decreases within the secondary coil. A current is induced to flow in the secondary coil.

Instead of opening and closing a switch that connects to a DC source, like a battery pack, a more effective way to change the magnetic field is to connect the primary coil to a source of alternating current. In this scheme, the current within the primary coil is continually changing, so the magnetic field is continually changing. The end result is that the induced current in the secondary coil is continually changing in the form of an AC output.

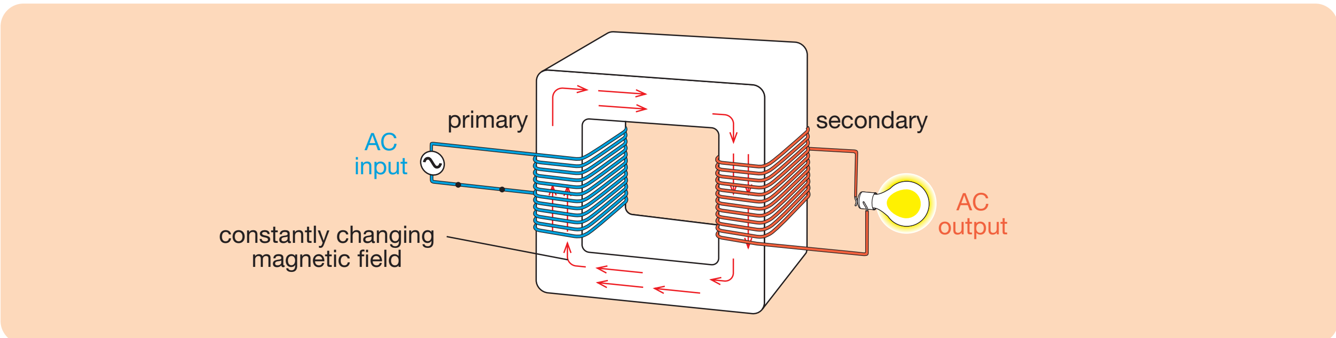


Figure C1.61: A source of alternating current (AC) connected to the primary coil ensures that the magnetic field is constantly changing within the secondary coil. An alternating current (AC) is maintained in the secondary coil.

Stepping Up or Stepping Down Voltage

A transformer is an AC device capable of transforming a voltage value from the primary circuit into another voltage value in the secondary circuit.

Early experiments with transformers revealed that the number of loops or turns of wire on the secondary coil compared to the number of loops of wire on the primary coil determined whether the voltage was stepped up or stepped down.

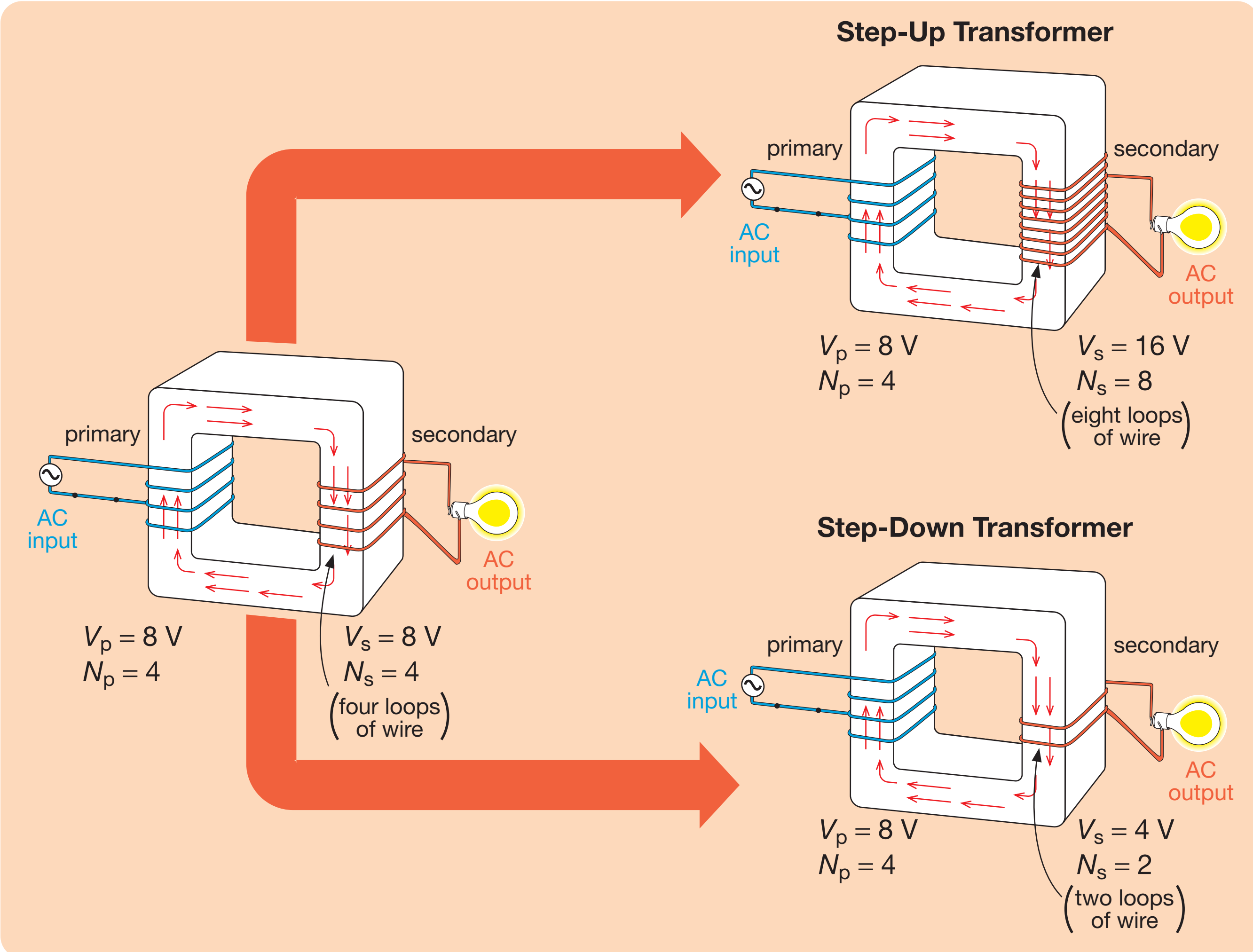


Figure C1.62

In Figure C1.62 the step-up transformer has twice the number of loops of wire on its secondary coil compared to the primary coil. Experiments have shown that if the secondary coil has double the number of loops as the primary coil, the output voltage of the secondary coil is double that of the primary coil. The same reasoning applies to the step-down transformer: if there are half the number of loops on the secondary coil as on the primary coil, the output voltage of the secondary coil is half the value of the primary coil. These ratios can be summarized by the following equation:

number of loops of wire on the primary coil

primary voltage (volts)

$$\frac{N_p}{N_s} = \frac{V_p}{V_s}$$

number of loops of wire on the secondary coil

secondary voltage (volts)

This description is incomplete because it is important to remember that energy is conserved. Voltage values cannot be stepped up or stepped down without some other variable responding to rebalance the output energy with the input energy. Transformers can be designed so that energy losses are minimized. Ideally, the input energy equals the output energy; therefore, the power into the primary coil equals the power out of the secondary coil.

As the following equations indicate, the current within the primary and secondary coils is the variable that counteracts changes to the voltage values to ensure that energy is conserved.

For an Ideal Transformer

power into primary = power out of secondary

primary voltage, primary current, secondary voltage, secondary current

$$V_pI_p = V_sI_s$$

Rearrange.

$$\frac{V_p}{V_s} = \frac{I_s}{I_p}$$

The earlier work with step-up and step-down transformers relates the primary and secondary voltages to the number of turns on each coil.

number of loops of wire on primary coil

$$\frac{N_p}{N_s} = \frac{V_p}{V_s}$$

number of loops of wire on secondary coil

These equations can be combined.

$$\frac{N_p}{N_s} = \frac{V_p}{V_s} = \frac{I_s}{I_p}$$

This is the equation for the ideal transformer.

This equation describes an ideal transformer with no energy losses. In reality, transformers lose a small fraction of the input energy in the form of heat; however, these energy losses are so small that this equation can be used to describe most commercially available transformers.

Example Problem 1.21

A large neon sign is powered by a high-voltage power supply. The power supply takes a 240-V input and then uses a transformer to increase the voltage to 12 000 V to operate the sign.

a. Does the power supply use a step-up or step-down transformer?

b. If the transformer has 125 turns of wire on the primary coil, determine the number of coils on the secondary coil.

c. The power supply requires 25.0 A of input current. Determine the output current that powers the sign.

Solution

a. Since the input or primary voltage is 240 V and the output or secondary voltage is 12 000 V, this is a step-up transformer.

b. $V_p = 240\ \text{V}$

$V_s = 12\ 000\ \text{V}$

$N_p = 125$

$N_s = ?$

$$\frac{N_p}{N_s} = \frac{V_p}{V_s}$$

$$N_s = \frac{N_pV_s}{V_p} = \frac{(125)(12\ 000\ \text{V})}{240\ \text{V}} = 6.25\times10^3$$

The secondary coil of the transformer has 6.25×10^3 turns of wire.

c. $V_p = 240\ \text{V}$

$V_s = 12\ 000\ \text{V}$

$I_p = 25.0\ \text{A}$

$I_s = ?$

$$\frac{V_p}{V_s} = \frac{I_s}{I_p}$$

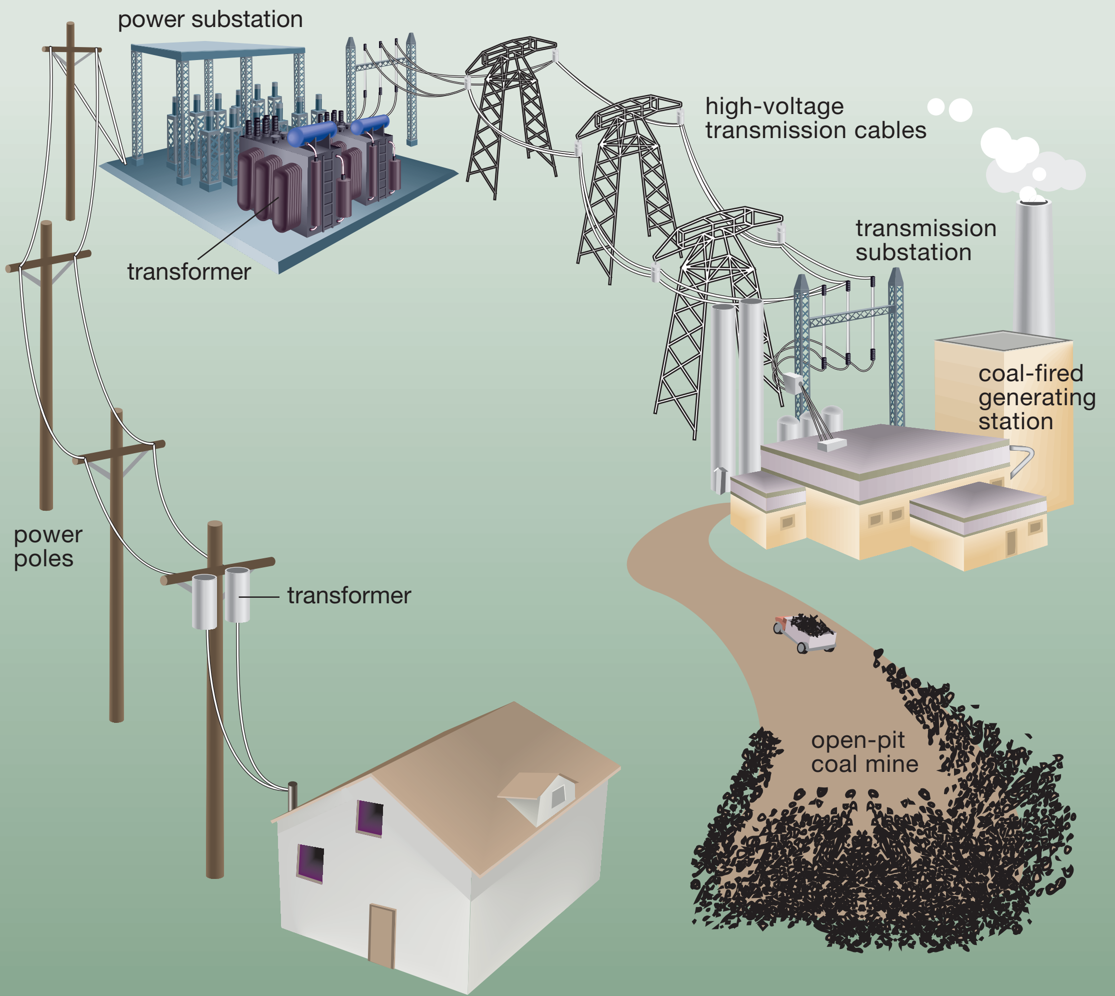
$$I_s = \frac{V_pI_p}{V_s} = \frac{(240\ \text{V})(25.0\ \text{A})}{12\ 000\ \text{V}} = 0.500\ \text{A}$$

The output current to power the sign is 0.500 A.

Practice

Use the following information to answer questions 50 and 51.

Transformers play a vital role in the distribution and transmission of electrical energy. In the following diagram, transformers can be seen playing a role at the generating station, at the power substation, and on the power poles.



50. The transformer on a power pole takes an input voltage of 4.00 kV and then delivers 240 V to a home.

  a. Is this device a step-up or step-down transformer?

  b. If there are 180 turns of wire on the secondary coil of this transformer, determine the number of turns of wire on the primary coil.

  c. If the maximum current supplied to the home is 100 A, determine the current supplied to the transformer.

51. The generator at the coal-fired generating station supplies the station's transformer with 20.0 kV. The transformer then boosts this voltage value to 230 kV for transmission.

  a. Is this device a step-up or step-down transformer?

  b. Most of the customers of the utility company only require 240 V or 120 V to run the appliances in their households. Explain why the utility company boosts the 20.0 kV from the generator to even higher values.

  c. If the power transmitted is 1.2 MW, calculate the current flowing through the transmission cables.

  d. Use the transformer equation to determine the current the generator is supplying to the transformer at the generating station.

  e. Check your answer to question 51.d. using a different equation.

1.5 Summary

Power is a quantity that describes the rate of doing work or using energy in joules per seconds or watts. Power was used throughout this lesson to describe the rate at which electrical energy is used in light bulbs, speakers, and a variety of household appliances. The kilowatt-hour is the unit traditionally used by electric utility companies to bill their customers.

The next time you use a kitchen appliance to make waffles, toast bread, or beat an egg, ask yourself this question: "Why is this appliance designed to operate on alternating current?" The answer has everything to do with reducing power losses during transmission and the central role played by transformers.

To reduce power losses in the transmission of electrical energy from the generating station to your home, it is essential that the current in the conducting cables be kept low by keeping the voltage high. However, a high transmission voltage means that there must be some way to reduce the voltage before it enters the homes of consumers. Transformers can reduce and increase voltages very effectively, with minimal energy losses, but transformers are AC devices. Since the entire distribution and transmission system depends upon the use of transformers, the system is based on alternating current.

1.5 Questions

Knowledge

1. Explain why it is misleading to call the bill from a utility company a "power bill."

2. Identify which coil in a step-up transformer has more turns of wire.

Applying Concepts

3. Explain why it is necessary to use alternating current with transformers.

4. Calculate the power dissipated by a toaster with a resistance of 14.0 Ω when it is plugged into a 120-V source.

5. A household clock rated at 5.0 W is operated for 365 days. Calculate the total electrical energy cost if the charge for electrical energy is 8.7¢/kW•h.

6. An ideal transformer has 100 turns of wire in the primary coil and 1000 turns of wire in the secondary coil. If the voltage and current in the primary coil is 120 V and 10.0 A, respectively, determine

- **a.** the voltage and current in the secondary
- **b.** the power in the primary and the secondary

7. Explain why it is advantageous to transmit power over large distances at high voltages.

Obtain the handout "Generating Electricity with Fossil Fuels" from the Science 30 Textbook CD. Use the information on this handout to answer question 8.

8. A family just purchased a new refrigerator that consumes 450 kW•h of electrical energy every year. The previous refrigerator was an old, inefficient model that consumed 605 kW•h of electrical energy every year.

- **a.** If the cost of electrical energy is 8.5¢/kW•h, how much money will this family save on their electric bill each year by using their new refrigerator?
- **b.** The utility company that provides electrical energy to this family uses a traditional coal-burning facility that pulverizes the coal into a fine powder before burning it to produce steam to drive the turbines. Calculate by how much the family will have reduced their annual emissions of $CO_2(g)$, $SO_x(g)$, $NO_x(g)$, and particulate matter by switching to the newer refrigerator.
- **c.** Consider your answers to questions 8.a. and 8.b. Which reduction do you think is the most significant?

Chapter 1 Summary

In Chapter 1 you saw how fields surround you and are an integral part of many of the technologies you use every day. Gravitational fields enable Earth to exert forces on objects without physically touching them. Earth's gravitational field keeps satellites in orbit, ensures that raindrops and snowflakes fall to the ground, and ensures that any ball you throw will always return to the surface of the planet. Electric fields enable lightning bolts to travel across the sky and ensure that electrons flow though the wires and circuits of every electrical device you have ever used. In nature, magnetic fields help to shield the surface of Earth from the harmful effects of the solar wind, and sometimes provide a path for these same particles to produce the spectacular displays called the northern lights. Magnetic fields also play a central role in a wide variety of devices, like motors, generators, headphones, microphones, speakers, and transformers.

The influence of electric and magnetic fields does not end here. In Chapter 2 you will see how these two fields can combine to produce the electromagnetic waves responsible for TV signals, microwave cooking, X-ray imaging, and even visible light. Stars emit electromagnetic waves. This is what enables the Sun to sustain life on Earth and provides scientists with valuable information about distant parts of the universe.

Summarize Your Learning

In this chapter you have learned a number of new terms, concepts, equations, and techniques for problem solving. You will have a much easier time recalling and applying the information you have learned if you take some time to organize it into some sort of pattern. Now that you have come to the end of this chapter, this is an appropriate time to focus on the patterns within the things you have learned. Since the pattern has to be in a form that is meaningful to you, you have some options about how you can create this summary. Each of the following options is described in detail in "Summarize Your Learning Activities" in the Reference section.

Option 1:	Option 2:	Option 3:	Option 4:	Option 5:	Option 6:
Draw a concept map or a web diagram.	Create a point-form summary.	Write a story using key terms and concepts.	Create a colourful poster.	Build a model.	Write a script for a skit (a mock news report).

Chapter 1 Review Questions

Knowledge

1. In this chapter you investigated three kinds of fields: gravitational fields, electric fields, and magnetic fields. Copy and complete the following table in your notes to summarize the key features of each kind of field.

Type of Field	General Description of Source(s)	General Description of Test Bodies	Equation That Describes Strength of Field	Example of How Field Assists You in a Task or Activity
gravitational field				
electric field				
magnetic field				

2. Refer to your answer to question 1 as you answer questions 2.a. and 2.b.
   a. Compare and contrast gravitational fields with electric fields.
   b. Compare and contrast electric fields with magnetic fields.
3. The concept of a field is a fundamental idea that has been referred to throughout Chapter 1. Distinguish between the following pairs of terms that all relate to the concept of a field.
   a. force and field
   b. field lines and field strength
   c. source of field and test body
4. Obtain the handout “Sketching Fields” from the Science 30 Textbook CD. Follow the instructions on this handout and add the required information.
5. Identify the common source for all magnetic fields.
6. Sketch a simple diagram of a DC electric motor. Label all the key parts.
7. Sketch a simple diagram of an AC generator. Label all the key parts.
8. Explain the differences between the output of a DC generator and the output of an AC generator. Use voltage-versus-time graphs to aid in your explanation.
9. With the aid of diagrams, describe how each of the following instruments is properly connected for taking measurements.
   a. voltmeter
   b. ammeter
   c. ohmmeter
10. Explain the meaning of *kilowatt-hour*. Provide an example of how this unit is used.
11. Transformers play a critical role in the transmission and distribution of electricity.
    a. Sketch a simple diagram that shows the basic parts of a transformer.
    b. With the aid of diagrams, illustrate how a step-up transformer differs from a step-down transformer.
12. Explain why electrical energy is distributed through transmission cables with very high voltage and why this system is designed to run with alternating current.

Applying Concepts

13. A car is parked with its engine off, but the car's owner forgot to turn off the headlights. The car's battery does 6000 J of work to move 500 C of charge from one contact of the headlight bulb to the other.

a. Calculate the voltage between the two contacts of the headlight.

b. Determine the energy emitted as heat and light by the bulb of the headlight.

14. In Roman mythology Mars (the god of war) had two attendants, Phobos (fear) and Deimos (panic). This is the origin of the names for the two moons of the planet Mars. Phobos has a mass of 1.08×10^{16} kg and an average radius of 1.35×10^{4} m, while Deimos has a mass of 1.8×10^{15} kg and an average radius of 7.5×10^{3} m.

a. Calculate the gravitational field strength at the surface of each moon.

b. Calculate the force of gravity that would act on an astronaut with a total mass of 107 kg on the surface of each moon.

c. Explain how the same astronaut can experience a different force of gravity on each moon even though the astronaut's mass is the same.

d. Sketch a diagram of each moon to illustrate the pattern of the gravitational field lines around each moon.

15. A van de Graaff generator is a machine that is able to put large quantities of charge on the metal globe on its top surface. During the winter months, when the air inside buildings is very dry, the globe on top of a van de Graaff generator can hold significant quantities of charge. For this question, consider that charge to be $+5.5 \times 10^{-6}$ C.

a. Calculate the number of electrons that were moved to produce this charge, and determine whether these electrons were added or removed from the large metal globe.

b. Calculate the strength of the electric field at the following distances from the centre of the large metal globe.

i. 40 cm

ii. 80 cm

iii. 120 cm

iv. 160 cm

c. A speck of dust with a charge of -2.5×10^{-12} C moves into each of the positions described in question 15.b. Calculate the magnitude and direction of the electric force on the dust speck in each location.

d. Explain how the same speck of dust can experience different amounts of electric force in each location.

e. Use your answers from question 15.b. to produce a graph of electric field strength versus distance from the centre of the large van de Graaff generator globe. Add the best-fit line.

f. Explain the reason for the shape of the resulting best-fit line.

g. Sketch a diagram to show the large van de Graaff generator globe, using arrows to represent the electric field vectors at each of the locations described in question 15.b.

16. Repeat the analysis outlined in all the parts of question 15 if the globe on the van de Graaff generator had a charge of -5.5×10^{-6} C.

17. A car speaker is connected to an AC circuit within the amplifier that supplies the speaker with 20.0 V. Consider the speaker to have a constant resistance of 4.0 Ω for all parts of this question.

   a. Calculate the electric current that flows through the speaker.
   b. Use your answer to question 17.a. to determine the power rating of this speaker.
   c. Use your answers to questions 17.a. and 17.b. to determine the electrical energy that is supplied to the speaker during 10.0 min of operation. Answer in joules.

18. Repeat the analysis outlined in the steps of question 17 using a speaker with a resistance of 8.0 Ω. Use your analysis to determine which speaker would sound louder.

Use the following information to answer questions 19 to 21.

A student uses the following equipment to complete a Science 30 lab activity:

- 3 resistors (500 Ω, 1000 Ω, and 1500 Ω)
- 6.0-V battery pack
- several leads for connecting the components of circuits
- digital multimeter capable of measuring volts, amperes, and ohms

These materials can be used to build either a series circuit or a parallel circuit.

19. The first task is to build a circuit that will incorporate all three resistors and use the minimum amount of electrical energy from the battery pack.
   a. Sketch a schematic diagram of this circuit. Be sure to include how the meter would be used to measure the current through all three resistors and the voltage across each of the three resistors.
   b. Using the data provided, calculate the total resistance for the resistors in your circuit.
   c. Use your answer to question 19.b. to calculate the current that would flow through all three resistors.
   d. Use your answer to question 19.b. to calculate the electrical energy that would be used by this circuit if it were allowed to operate for 10.0 min.

20. Repeat the analysis outlined in the parts of question 19 for a circuit that will incorporate all three resistors and will use the maximum amount of energy from the battery pack.

21. Refer to your answers to questions 19 and 20. Determine whether it was the series circuit or the parallel circuit that used the maximum amount of energy.

Use the following information to answer questions 22 to 25.

The Second Price Tag

When most people purchase a major appliance, the main consideration is the cost to buy the appliance, which is printed on the price tag. Another consideration is the cost to operate the appliance over its lifetime. This cost could be called the second price tag because, after the initial purchase, this cost will be paid month after month on the electric bill. Although more energy-efficient appliances may have a slightly higher purchasing cost, this is balanced against their lower operating costs.

Environmental Considerations

Another set of considerations is the impact the use of an appliance will have on the environment. In Alberta, most electricity is generated by burning coal or other fossil fuels to drive a turbine that turns the shaft of a generator. This means that every kilowatt-hour of electricity has an environmental consequence in terms of the emissions of $CO_2(g)$, $NO_x(g)$, $SO_x(g)$, and particulate matter.

Comparison Shopping

The following data was collected for two 22-cubic-foot refrigerators with top-mounted freezers.

Refrigerator	Model A	Model B
Cost to Purchase	$1699.99	$1200
Annual Energy Consumption	435 kW•h	545 kW•h
Life Expectancy of Refrigerator	17 years	17 years
Lifetime Operating Costs		
Environmental Considerations		

22. Use 9.3¢/kW•h to calculate the following costs.

a. the lifetime operating costs for Model A

b. the lifetime operating costs for Model B

23. Obtain the handout "Generating Electricity with Fossil Fuels" to calculate the mass of $CO_2(g)$, $SO_x(g)$, $NO_x(g)$, and particulate matter emitted for Model A if the electricity is generated using a traditional coal-fired generating station that uses pulverized coal.

24. Repeat the analysis outlined in question 23 for Model B.

25. In this set of questions you have examined three criteria to be considered when buying a major appliance: the cost to purchase, the lifetime operating costs, and some environmental considerations.

a. How do you think most consumers rank these three criteria?

b. How do you think these three criteria should be ranked in the minds of consumers?

c. If you were purchasing a new refrigerator, would you buy Model A or Model B?

26. The doorbell of a home requires 10.0 V to operate. A transformer is used to connect the doorbell to a 120-V circuit within the home. The doorbell transformer has 500 turns on the primary coil and supplies the doorbell with 900 mA of current.

a. Determine whether the transformer features a step-up or step-down design.

b. Calculate the number of turns on the secondary coil.

c. Calculate the current that is drawn from the 120-V household circuit to operate the doorbell.

Use the following information to answer questions 27 to 32.

Obtain the handout "An Energy-Conversion Device" from the Science 30 Textbook CD. Use the information on this handout to answer the next six questions.

27. Identify the proper name for the device shown in Part 1 of the handout.

28. Describe the rotation of the loop in detail from step 1 through to step 4 in Part 1 of the handout. Be sure to explain the direction of motion of the highlighted section of the loop in each step.

29. Refer to the diagram for Modification 1 in Part 2 of the handout. Carefully compare this diagram with step 1 in Part 1, and explain how this modification will affect the motion of the loop.

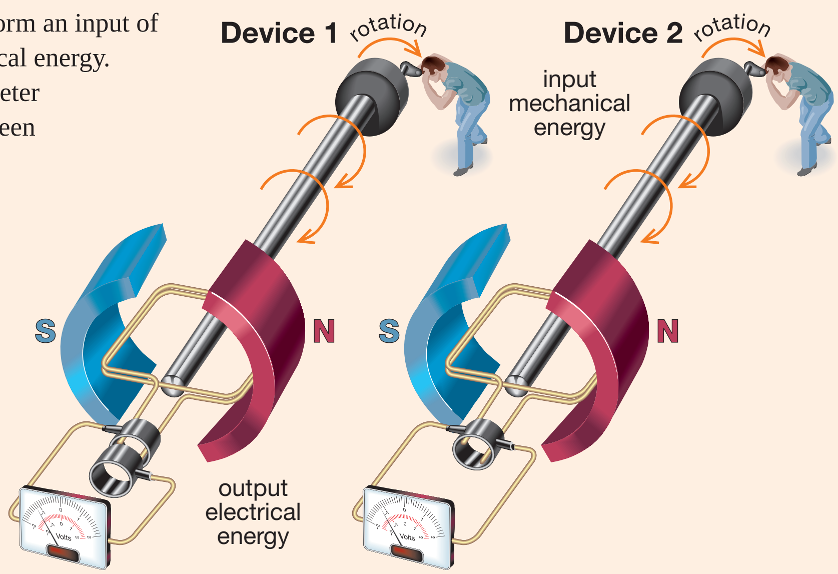
30. Refer to the diagram for Modification 2 in Part 2 of the handout. Carefully compare this diagram with step 1 in Part 1, and explain how this modification will affect the motion of the loop.

31. Refer to the diagram for Modification 3 in Part 2 of the handout. Carefully compare this diagram with step 1 in Part 1, and explain how this modification will affect the motion of the loop.

32. Refer to the diagram for Modification 4 in Part 2 of the handout. Carefully compare this diagram with step 1 in Part 1, and explain how this modification will affect the motion of the loop.

Use the following information to answer questions 33 to 35.

The diagram shows two devices that transform an input of mechanical energy into an output of electrical energy. Note that the output displayed on the voltmeter changes as the loop is forced to rotate between the two stationary magnets.



33. Carefully examine the illustration for Device 1.

a. Identify the proper name for this device.

b. Sketch a graph of voltage versus time to describe the output from this device.

c. The number of rotations the loop is forced to make every minute can be increased. Sketch a graph of voltage versus time to show the output from the device under these circumstances.

34. Carefully examine the illustration for Device 2.

a. Identify the proper name for this device.

b. Sketch a graph of voltage versus time to describe the output from this device.

c. The number of rotations the loop is forced to make every minute can be increased. Sketch a graph of voltage versus time to show the output from the device under these circumstances.

35. The stationary magnets on either side of the rotating loops play an essential role in the operation of each of these devices. Without these magnets, no electrical energy would be produced if the loops were forced to rotate; yet, these stationary magnets do not even touch the loops. Explain how the stationary magnets are able to exert forces and produce an electric current within the loop even though there is no physical contact.